A NEW FUNDAMENTAL TEST OF QCD WITH DRELL-YAN MEASUREMENTS IN POLARIZED P+P COLLISIONS 20120083DR

Introduction: A new fundamental test of Quantum Chromo Dynamics (QCD) can be performed by comparing the transverse single spin asymmetries from polarized deep inelastic lepton scattering (DIS) and the Drell-Yan (DY) process in polarized proton-proton (p+p) collisions[1]. The spin asymmetry is now well known to be non-zero for DIS, but is unknown for the Drell-Yan production[2]. We propose to carry out **the world's first measurement of transversely polarized Drell-Yan** (pol-DY) production at Fermilab and the state-of-the-art next-to-leading-order (NLO) theoretical calculations relevant to understanding the data acquired. The results will lead to **a major breakthrough** in our understanding of QCD dynamics and may provide a solution to the "proton spin crisis."

The Problem: Spin plays a key role in the determination of the properties of fundamental particles and their interactions. However, two outstanding spin puzzles have challenged our understanding of QCD for over 30 years. We argue below that there is an **exceptional opportunity** that will both allow us to carry out a novel test of QCD and possibly resolve these two long-standing problems.

The first surprise came in the 1970s when very large (~50%) "left-right" asymmetries were discovered in transversely polarized high-energy p+p→π+X reactions, while all QCD based models then predicted no significant asymmetry (<<0.1%). More recent experiments have shown that the asymmetry persists up to center of mass energy of 500 GeV. **The second surprise** came in 1988, when measurements of the longitudinal spin asymmetry at the EMC experiment showed that the spin of the quarks only contributes about 30% (~100% expected) of the total proton spin! This is known as the "proton spin crisis". Major follow-up experimental programs include polarized DIS experiments at DESY, SLAC, JLab, CERN and polarized p+p experiments at FNAL and BNL, as well as a possible new polarized Electron-Ion-Collider facility. Solving these two outstanding spin puzzles is the focus of all current and future high-energy spin programs.

A new physics view has started to emerge, indicating that the solutions to these two seemingly uncorrelated puzzles could have a common origin. Recent results from the RHIC spin program at BNL show that the gluon spin contribution is small, leaving only the orbital motion of quarks and gluons to contribute the missing component of the proton spin. Also, the first experimental observations of a non-zero Sivers "left-right" asymmetry in DIS have been reported[3]. This asymmetry is related to the correlation between the proton spin direction and the quark orbital angular motion[4]. Significant recent theoretical progress has been made to understand the Sivers asymmetry from the first principles of QCD. If the observed transverse spin asymmetry comes from a large orbital angular momentum of quarks and gluons, this would also provide a natural solution to the proton spin crisis. **A satisfactory resolution of these two puzzles would be a major breakthrough in our understanding of hadron structure and QCD.**

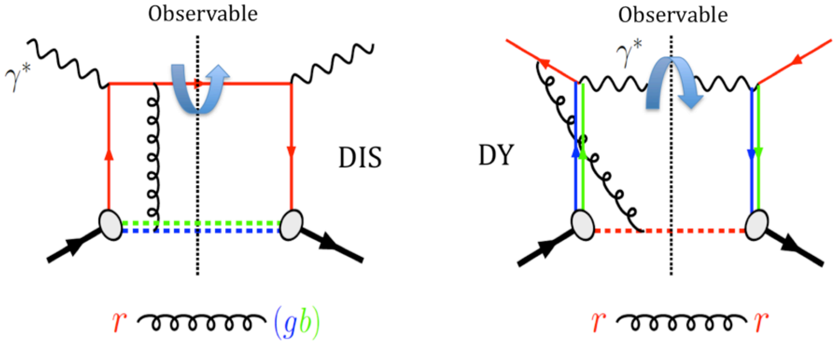


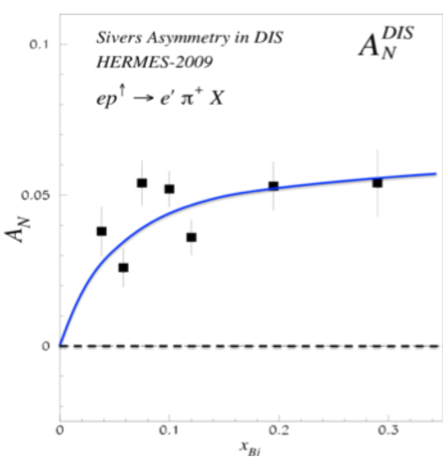
Figure 1. QCD example diagrams for the opposite-color-charge attractive final-state interaction in DIS (left) and the same-color-charge repulsive initial-state interaction in the Drell-Yan process (right) that produce the expected spin asymmetry sign change (schematically illustrated by the blue curved arrows).

Spin asymmetry measurements with **polarized Drell-Yan** are an urgently needed **new experimental approach** that will advance our understanding of the origin of spin and lead us to the **next significant development in the theory of strong interactions**. Leading order (LO) QCD predicts that the asymmetry in **pol-DY production has the opposite sign** to what has been observed in polarized DIS; see Figure 1. Performing polarized Drell-Yan experiments to determine this sign change has become **one of the top priorities for the worldwide hadronic physics community. LANL has been playing a leading role at this frontier**, advocating new programs at RHIC and other facilities[1,5], carrying out polarized measurements at RHIC and JLab, and organizing the most recent of several dedicated workshops, at Santa Fe[6]. If funded, this project would allow us to accomplish the world's first pol-DY measurement and related state-of-the-art NLO theoretical calculations and interpretation of the data.

Proposed innovation: Carry out the world's first polarized Drell-Yan measurement at Fermilab and NLO theoretical analysis.

<u>*Experimental work:*</u> Fermilab has the world's highest intensity (unpolarized) proton beam for fixed targets. We will develop a new pol-DY experiment, based upon the E906 setup, but with a polarized proton target operated at the world's highest luminosity. We will carry out a detailed detector layout and physics simulations to evaluate the signal and background rates in order to optimize the physics sensitivity; see Figure 2. A full physics beam use proposal will be submitted to Fermilab to perform the experiment in FY14. The needed high density and high polarization proton (NH_3) target will be designed at LANL, based upon the state-of-the-art technology developed at UVa/SLAC/JLab. Cryogenic design expertise and experience with polarized targets exists within our team (Jiang), and the target design work will be done in close collaboration with world experts, Dr. Don Crabb and Dr. Jian-Ping Chen. Similar to a polarized NH_3 target used at LANL, the superconducting magnet and cryostat will be commercially manufactured.

<u>*Theoretical work:*</u> Although the leading order picture strongly implies an expected experimental result, NLO corrections could modify it considerably, as they almost double the unpolarized cross section. We have been active in the past regarding resolution of the proton spin crisis[7] and have also developed NLO calculations to describe Drell-Yan production in unpolarized p+p collisions[8]. We will extend our NLO calculations to include the Sivers distribution functions necessary for the analysis of the upcoming pol-DY data. Specifically, we will include the next higher-order correction process that is expected to contribute: quark-gluon Compton scattering. This work is essential for interpreting the experimental data, as it may produce sizable corrections to the current perturbative QCD paradigm of exact sign reversal and equal magnitude



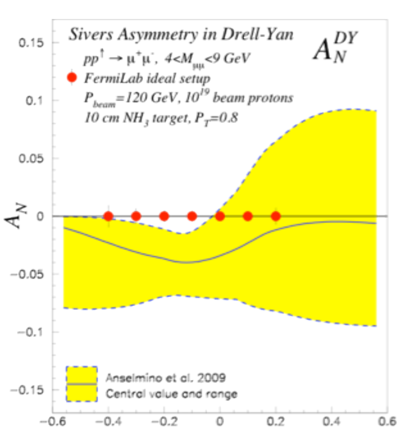


Figure 2. Left: Large Sivers asymmetry in DIS measured by the HERMES experiment for π^+ production. Right: Preliminary study of pol-DY asymmetry with 120 GeV/c beam. The red solid circles show the expected statistical uncertainties of the proposed experiment at Fermilab, which can clearly test the sign change in the Drell-Yan spin asymmetry and its magnitude.

of the asymmetry, and affords a unique opportunity to determine the strength of the various contributions. Toward the end of this project we will carry out a theoretical analysis of the initial pol-DY experimental data.

Why LANL: The P-25 group has 25 years of experience of leading Drell-Yan experiments at Fermilab. Members of the team have made the world's best unpolarized DY production cross-section measurements in p+p collisions. We also have 15+ years of experience leading polarized p+p spin physics experiments at RHIC and using DIS reactions on polarized targets at Jefferson Lab. Our group is among the leaders in quark and gluon Sivers asymmetry measurements at both RHIC and JLab. Our long-time collaborators include world-leading experts in polarized targets, nucleon spin physics and DY experiments. LANL T-2 theorists contributed significantly to the theoretical understanding of the Drell-Yan production at NLO and the partonic spin decomposition of the nucleon.

Why now: A unique opportunity exists to perform the world's first pol-DY measurements following the completion of the current E906 experiment in FY13. Fermilab has the highest intensity high-energy proton beam, which will produce the most precise Drell-Yan measurement possible, surpassing proposed experiments at all other facilities. E906 will provide fully functional tracking detectors for the new polarized DY measurement in FY14.

Methods and anticipated results:

1. Defend a new proposal to Fermilab for a polarized Drell-Yan experiment in FY13.
2. In collaboration with the UVa and JLab target groups, design and contract construction of a new polarized proton target for the experiment.
3. Obtain the first results of sign change and magnitude of the asymmetry in pol-DY.
4. Perform LO and NLO calculations of spin asymmetry for all pol-DY production mechanisms, and provide theoretical interpretations for the experimental data.

Importance for the Laboratory and Nation: The proposed work is central to the FY12 LDRD Strategic Investment Plan for the BSM category. We will perform the world's first polarized Drell-Yan measurement, exploring a novel aspect of QCD dynamics. Development of a state-of-the-art polarized target would bring new S&T capabilities to LANL. This is a timely opportunity for us to initiate a polarized DY program via **a strategic partnership with Fermilab and continue LANL's leadership role** in theoretical and experimental medium energy nuclear physics. We expect that a successful LDRD project would be followed by a major multi-year nuclear physics program with polarized DY, supported by the DOE Office of Science.

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